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No. 548

FLIGHT TESTS OF A BALANCED SPLIT FLAP WITH PARTICULAR REFERENCE TO RAPID OPERATION

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SUMMARY

The flight path of a small parasol monoplane equipped with a special type of balanced split flap has been determined for a series of glides during which the time taken to deflect or retract the flap was varied from 1 to 15 seconds in order to study the effect of the time taken to complete a flap movement on the motion of the airplane between the start of the flap movement and the attainment of steady flight with the new flap setting. The measurements showed that all flap movements accompanied by a change of velocity, such as is necessary when the flap is retracted while flying at the low speed of the airplane with the flap extended, led to an initial displacement of the flight path in a direction opposite to that ultimately obtained. The distance the airplane traveled before its actual path crossed, in the desired direction, the path it would have maintained had there been no flap movement appeared to be practically independent, within reasonable limits, of the time taken to complete the flap movement and appeared to depend primarily on the velocity change. For a velocity change from 45 miles per hour to 55 miles per hour corresponding to the difference in minimum speeds with the flap extended and flap retracted this distance was about 800 feet. The change in attitude and vertical velocity of the airplane during the initial stage of the transition from one steady condition to another depended to some extent on the abruptness of the flap motion so that instantaneous operation appeared less desirable than a somewhat gradual operation. With a flap or with another glide-angle-control device that changes only the drag of the airplane and does mot cause a change in velocity, instantaneous operation of the device may be desirable in permitting changes to the flight-path angle to be quickly completed.

It was found that the balanced split flap used in the investigation gave an appreciable reduction in the hinge

moment, while having approximately the same lift and drag characteristics as the plain split flap.

INTRODUCTION

Experience gained through previous flight work with wing flaps had indicated the need for study of the effect of the operational characteristics of flaps on their usefulness. It is obvious that flaps with large hinge moments, for which 20 or more seconds are required to obtain full deflection, are of limited utility because of the distance which the airplane will travel while they are being deflected. On the other hand, it was appreciated that, if a flap were retracted instantaneously while flying at the minimum speed with the flap extended, the lift would not be sufficient to sustain the airplane until the velocity was increased and the airplane might be placed in a dangerous situation before the new equilibrium conditions were attained. No specific information was available, however, to show the actual flight path and velocities during such a maneuver.

In order to obtain flight information concerning the effect of the time of operation of a flap on the motion of an airplane, three series of tests were performed with a Fairchild 22 airplane equipped with a balanced split flap (see reference 1) that can be easily and quickly operated. For these tests the actual flight path of the airplane was recorded during and following movements of the flap requiring from 1 to 15 seconds. In the first series of tests the airplane was placed in a glide at its low speed with the flap extended. During this glide the flap was retracted and the speed increased to the stalling speed for the new flap position. In the second series the initial glide was made with the flap retracted; it was then lowered and the speed reduced. In the third series the speed was maintained constant and the flap was used solely as a glide-angle control.

As the balanced split flap used in the investigation had not been previously flown, an additional series of tests was made to supplement the wind-tunnel information on certain of its aerodynamic characteristics. The effect of the flap on the maximum lift coefficient of the airplane and the flap hinge moments were determined and its effect on the longitudinal balance and stability was noted.

APPARATUS AND METHOD

The Fairchild 22 airplane used in the tests is a small parasol monoplane. It was equipped with a special wing fitted with the balanced split flap. The lay-out of the wing and flap is shown in figure 1. The flap has a chord of 16.2 percent of the wing chord and extends across 90 percent of the wing span, 3 feet being cut out at the center section to provide clearance over the pilot's cockpit. For lateral control, retractable ailerons (reference 2) were provided. The wing was installed on the airplane with an angle of wing setting of 0.9° and a dihedral angle of 3°. The installation is shown in figure 2. Figures 3, 4, and 5 are views of the airplane showing the flap and ailerons. General characteristics of the airplane pertinent to the tests are given in table I.

The flap was operated through a linkage consisting of a series of push-pull rods and bell cranks from a lever mounted on the left side of the pilot's cockpit. The relative motion of the control lever and flap is shown in figure 6.

For the determination of the flight path during the tests of flap operation, the method described in reference 3 involving the use of a recording phototheodolite was employed with some modifications dictated by the particular requirements of the present tests. The flight path thus obtained was corrected to zero wind condition by assuming that the wind velocity was equal to the difference between the horizontal component of the ground speed as given by the theodolite and the horizontal component of the air speed as recorded in the airplane. The time of operating the flap was found directly from a record of flap position against time.

The lift and drag characteristics of the airplane with the flap both retracted and extended at angles of attack in the vicinity of maximum lift were determined by glide tests with the engine idling. The formulas $C_L = L/qS$ and $C_D = D/qS$ were used to reduce the lift and drag to coefficient form.

The force required to operate the flap was determined at several speeds and for several flap deflections by a spring balance attached to the flap-control handle. The

fraction of this force necessary to overcome the weight of the flap was determined by similar measurements on the ground. From the length of the flap-operating lever and the mechanical advantage of the flap lever over the flap itself (given by the slope of the curve in fig. 6), the aerodynamic hinge moment of the flap was found. This moment was reduced to coefficient form by use of the formula $C_H = M_f/qSc$.

The effect of the flap on the longitudinal trim and static stability of the airplane was determined by measurement of the stick forces and elevator position throughout the speed range with the flap both retracted and extended.

RESULTS AND DISCUSSION

Effect of Flap Operation on the Flight Path

Figure 7 shows the effect of operating the flap as rapidly as possible. The two upper flight paths represent the motion of the airplane subsequent to the retraction of the flap while flying at low speed with the flap extended. The lower curve represents the flight path when the flap is extended in an attempt to reduce the air speed and steepen the flight path. The curves show that the immediate response of the airplane to a quick movement of the balanced flap was in the opposite direction to that ultimately obtained and that a distance of the order of 800 feet was traversed before the airplane crossed over the path it would have traveled had no flap movement been made.

Of the two paths shown in the upper part of figure 7, one represents the case where normal elevator movements are made by the pilot in an attempt to make the transition to the ultimate path as safe as possible. The other represents the boundary condition; that is, the condition in which the inherent longitudinal stability is the only factor involved in defining the path. Of necessity, only the first oscillation is shown. It was noted in flight that in neither case was there any tendency of the airplane to spin. That retracting the flap suddenly while in low-speed flight close to the ground may be dangerous is indicated by the maximum vertical velocity during the transition, which is 25 feet per second even in the case where the pilot attempted to hold this component of speed

as low as possible. The nose-down attitude of the airplane of $10-1/2^{\circ}$ at this speed makes conditions even more dangerous. In addition to both these factors, there is the surprise element to a pilot who is not aware of the probable path and retracts the flap, expecting the flight-path angle to decrease immediately. Finally, unless decision is made when the airplane is still about 800 feet away from an obstacle or 200 feet above the ground, there is no advantage in retracting the flap. In fact, within this distance, movement of the flap would simply increase the speed of contact from 45 miles per hour to at least 55 miles per hour. There is, of course, a possibility that with practice a maneuver such as that shown by the elevator-free path could be utilized by the pilot to avoid obstacles, but consideration of this case is beyond the scope of the present paper.

Figure 8 represents the data obtained for the remainder of the tests in which the flap was retracted; figure 9 gives similar data for tests with the flap extended. The two upper curves (A and B) of each figure illustrate the effect on the flight path of the time taken to complete a flap movement. The air speeds were approximately the same for all four runs, those for figure 9 occurring, of course, in the reverse order to those of figure 8. The speed change in each case is representative of a change from the stalling speed with the flap in one position to the new stalling speed with the flap in the other position.

It appears desirable, before proceeding with the discussion of figures 8 and 9, to consider the sequence of events following the flap movement as shown diagrammatically in figure 10. The figure illustrates the case in which the flap is retracted during steady flight and the velocity of the airplane is increased simultaneously with the flap movement. The airplane, prior to displacement of the flap, is gliding along path 1-2. At point 1, presumably because he desires to change to path 1-1', the pilot retracts the flap. Actually, the desired path will never be attained. The airplane, because of the decrease of lift, will immediately fall below the original flight path and travel along some path such as the one indicated by the solid line. At some time after the flap is moved, conditions will become steady and the airplane will attain path 2-2'. Not until point 2 is reached, however, will the airplane be in a better position than it would have been in had no flap movement been made.

The principal features shown by the tests, for which curves A and B of figures 8 and 9 are representative, are that, although the distance traveled between points 1 and 2 varies appreciably because of differences in piloting, it is practically independent of the time taken for the flap movement up to 10 seconds and that the violence of the motion during the transition is decreased when the flap is moved slowly. From these results, it would appear that the flap should be moved as slowly as possible; but, when it is considered that it would be desirable to have the airplane in steady flight by the time point 2 is reached, it is evident that the time taken to travel from point 1 to point 2 represents the optimum length of time in which to complete the flap movement.

Consideration of the information obtained in the flight tests suggested a means of computing the optimum time to complete a flap movement for the general case. Reference to the case illustrated in figure 10 shows that the final velocity of the airplane is greater than the initial velocity and therefore the kinetic energy is greater. In order to have attained the additional kinetic energy, the airplane must have lost a corresponding amount of potential energy or equivalent altitude A_1 given by the equation

$$A_1 = \frac{(V_f^2 - V_i^2)}{2g}$$

where V_f is the final velocity and V_i the initial velocity. In addition to the altitude lost due to the increase in velocity, there is an altitude loss representing the energy needed in overcoming the drag between points 1 and 2. For convenience, this loss is considered as consisting of two parts: A_3 representing the loss of altitude that would have been incurred even had the change of velocity and the corresponding change of altitude been instantaneous and the airplane had traveled a path 2-2' the entire distance D in the steady glide, and A_2 representing the loss of altitude corresponding to the energy expended in reducing the vertical velocity to the final value, and the additional work done during the transition because conditions are never as assumed in connection with the altitude loss A_3. The value A_3 is dependent on A_1 and A_2 and on the lift-drag ratios of the airplane for the initial and final gliding conditions. It is not necessary to calculate A_3. The altitude loss A_2 depends

in part on the piloting technic and can be obtained only from experiment. A study of the results from which figure 8 was drawn indicates that A_2 is almost independent of the time taken to operate the flap and is never likely to be less than 10 feet, even after considerable practice. With a knowledge of A_1, A_2, and the lift-drag ratios for the initial and final conditions, the horizontal distance D may be computed from the equation

$$D = \frac{(A_1 + A_2)\ (L/D)_f\ (L/D)_i}{(L/D)_f - (L/D)_i}$$

As A is small relative to D, the distance traveled along the flight path between points 1 and 2 is approximately equal to D and the time taken to travel from point 1 to point 2 may be computed from the equation

$$T = \frac{2D}{V_i + V_f}$$

The foregoing analysis refers to the case where the flap is retracted. For the case where the flap is extended, the conditions are reversed. Calculations of this type on the airplane tested indicate that 6-1/2 seconds would be the optimum time in which to move the flap when the speed change corresponds to the difference between stalling speeds for the two flap positions.

It is evident from the foregoing discussion that, if the speed were kept constant during the flap movement, A_1 would be zero and almost immediate control of the flight-path angle would be attained. It would obviously be impossible to maintain the speed constant if a flap that increased the lift coefficient, as in the present case, were retracted at minimum speed. Several forms of gliding-angle controls have been developed that do not increase the lift and for which this consideration is important. Flight paths illustrating such a case are shown by the lower curves (C) of figures 8 and 9. It is evident from figure 9C that almost immediate change of flight path in the desired direction can be obtained if the velocity is maintained constant. There is considerable difficulty, however, in maintaining constant speed when the flap is operated, owing particularly to the change in angle of attack required to maintain a constant lift coefficient. Thus, in the reverse maneuver shown in figure 8C, there

was a considerable variation in speed with the result that a distance of 550 feet was traversed before the airplane finally crossed and remained above the extension of the original flight path.

Characteristics of the Balanced Split Flap

Figure 11 gives the lift and drag characteristics of the Fairchild 22 airplane for angles of attack in the neighborhood of the stall and shows the effect of the balanced split flap. The maximum lift coefficient of the airplane was increased through use of the balanced split flap from 1.49 to 2.17. The stall, as expected, occurred at the same angle of attack with or without the flap. The drag coefficient at maximum lift, with the propeller idling, was increased from 0.23 to 0.43 by lowering the flap. As the percentage increase in the drag coefficient was greater than the percentage increase in lift coefficient, the L/D ratio at maximum lift was decreased from 6.5 to 5.0.

In order to illustrate the effect of the balanced split flap on the gliding performance of the airplane the velocity diagram (fig. 12) has been included. This diagram shows that the low speed of the airplane was reduced from 51 miles per hour to 43 miles per hour and that the glide angle at low speed was increased from $8\text{-}1/2^\circ$ to 11° by use of the flap. The curves have been prepared from the flight data for the airplane with flap up and flap down and it should be appreciated that were the comparison made between an airplane without flaps and one with flaps the additional wing weight due to the weight of the flap installation would have to be considered. The installation of flaps increases the weight of the wings about 50 percent or, for the airplane in question, about 100 pounds. Thus, for a given disposable load, the low speed of the airplane without flaps would have been 49.5 miles per hour as against the 51 miles per hour given for the flap-up condition. The glide angle at low speed is independent of the weight.

Figure 13 gives the attitude angles of the airplane for gliding flight. These curves show that when the flap is lowered the pilot must expect the nose of the airplane to lower. The nosing-over tendency is least when the angle of attack is kept constant and the speed decreased as the flap is lowered. If the speed is kept constant, however, the airplane will nose over about 12°.

The flap-operating force is shown in figure 14 for several air speeds and the corresponding flap hinge-moment coefficients are shown in figure 15. Only the solid portions of the curves represent experimental data; the dashed portions are extrapolations to the limits of travel. A comparison between the flight results and full-scale-tunnel data (reference 4) for a plain split flap on the same airplane indicates that the hinge moments of the balanced split flap are about two thirds of those for the plain split flaps, agreeing with the predictions made on the basis of the small-scale tests of reference 1.

The effect of the balanced split flaps on the longitudinal stability and control characteristics of the Fairchild 22 airplane is of interest as an illustration of the manner in which the large pitching moments of flaps may manifest themselves. Figure 16 shows the elevator forces with the standard horizontal tail surfaces with the stabilizer set full tail heavy for the flap-up and flap-down conditions with both power on and power off. With flap up the elevator forces were normal. With power both on and off there was one speed at which the airplane would balance with stick free and the slope of the stick-force curves was negative throughout the speed range. With the flap down there was no speed at which the airplane would balance with the stick free with power either on or off within the speed range covered although, with power on, indications are that the airplane probably had a balance speed of about 73 miles per hour. In addition, the flap changed the slope of the curves from negative to positive, with power on at speeds above 55 miles per hour and with power off at speeds above 64 miles per hour. It is possible, by adjustment of the stabilizer, to shift the stick-force curves in the vertical direction; the positive slopes of the curves have therefore greater significance than the fact that no balance speeds were obtained with the stabilizer setting tested. If a stick-free balance speed of, for example, 64 miles per hour, with the power off, were obtained by a suitable stabilizer adjustment, the airplane would still be dangerous to fly as any increase of speed from this would require that the stick be pulled back to prevent the airplane from going into a dive. With the stable or negative slope to the stick force, the airplane would automatically tend to return to the balance speed.

Instability of the stick-force curve as encountered with this airplane with the flap down is usually associated with an unstable slope of the pitching-moment coeffi-

cient for the airplane. The measured elevator angles for the flap down and power off, which are also shown in figure 16, indicate, by the fact that the elevator was moved progressively trailing edge down in order to increase the speed, that in this case the airplane had a stable slope to the pitching-moment coefficient curve. Subsequent tests have shown that this difficulty with the longitudinal stability is not confined solely to the type of flap used in these tests but is likely to be encountered with any flap, particularly if the flap is installed on an airplane not originally designed to receive it.

An analysis of the design of horizontal surfaces in conjunction with wings equipped with flaps, which will be completed and reported later, indicates that it is necessary to consider the maximum lift coefficient that can be obtained from the tail plane with free elevator. The difficulty with the present flap installation is that with the elevator free the horizontal tail surface is too small to provide the tail moment required to balance the wing pitching moment at small angles of attack with the flap down, although with elevator fixed the area is sufficient to make the airplane statically stable.

In order to make the airplane satisfactory for the tests a trimming tab was installed on the elevator to change the elevator angle for zero stick force. Figure 17 shows curves of elevator control force and position after the tab was installed. Difficulty caused by the unstable slope of the stick-force curve was avoided by not exceeding 70 miles per hour with the flap down during the tests.

CONCLUSIONS

1. For flap movements accompanied by a change of lift characteristics, and consequently of velocity, there is an appreciable delay in obtaining a desired change in glide angle even though the flap is operated instantaneously. Immediate control of the glide path is obtained only when the speed is maintained constant during the flap movement.

2. When the speed is changed, the deviation from the desired path during the transition increases in proportion to the rapidity with which the flap is moved so that, with a high-lift flap, abrupt retraction at speeds less than the minimum speed with the flap retracted may be dangerous if practiced close to the ground.

3. The balanced split flap increased the maximum lift coefficient of the Fairchild 22 airplane from 1.49 to 2.17. The increase is about equal to that of a plain split flap of the same dimensions.

4. The design of tail surfaces is more critical with flaps than without, and there is a certain amount of danger involved in the installation of flaps on an airplane not originally designed to receive them.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 14, 1935.

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1. Wenzinger, Carl J.: Wind-Tunnel Investigation of the Aerodynamic Balancing of Upper-Surface Ailerons and Split Flaps. T.R. No. 549, N.A.C.A., 1935.

2. Soulé, H. A., and McAvoy, W. H.: Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps. T.R. No. 517, N.A.C.A., 1935.

3. Thompson, F. L., Peck, W. C., and Beard, A. P.: Air Conditions Close to the Ground and the Effect on Airplane Landings. T.R. No. 489, N.A.C.A., 1934.

4. Wallace, Rudolf: Investigation of Full-Scale Split Trailing-Edge Wing Flaps with Various Chords and Hinge Locations. T.R. No. 539, N.A.C.A., 1935.

TABLE I

CHARACTERISTICS OF THE FAIRCHILD 22 AIRPLANE WITH SPECIAL WING EQUIPPED WITH BALANCED FLAPS

Wing:

Area	162 sq.ft.
Span	30 ft.
Chord	5 ft. 6 in.
Aspect ratio	5.55
Airfoil section	N-22
Angle of wing setting	0.9°
Dihedral	3.0°

Balanced Flap:

In 2 sections leaving 3-foot cut-out over pilot's cockpit.

Span (each section) . .	13 ft. 6 in. or 90 percent b/2.
Chord	10-3/4 in. or 16.25 percent c.
Airfoil section . . .	Ordinates given in table II.
Hinge location . . .	2.15 in. or 3.25 percent c aft L.E. of flap. 1.61 in. or 2.44 percent c below chord of flap.
Maximum deflection . .	56°.

TABLE I (Continued)

Lateral Control System:

Retractable aileron:

Chord location	4 ft. 2-1/2 in. or 7.65 percent c aft L.E. of wing.
Span	7 ft. 6 in. or 50 percent b/2.
Hinge-axis location . .	3 ft. 7 in. or 65 percent c aft L.E. of wing.
	1 ft. 1/8 in. or 18.4 percent c above chord of wing.
Maximum deflection . .	8-1/16 in. or 12 percent c from upper wing surface.

Horizontal Tail Surfaces:

Total area (exclusive of elevator tabs)	26.2 sq.ft.
Span	10.0 ft.
Aspect ratio	3.8
Stabilizer area	15.8 sq.ft.
Stabilizer range	-4.0° to 2.1°
Elevator area (exclusive of tabs). . .	10.4 sq.ft.
Elevator range	$\pm 30^{\circ}$
Tab area	0.79 sq.ft.
Tab setting	13°
L.E. of wing to elevator hinge axis . .	14.74 ft. or 2.68 c

Weight . . . . 1,674 lb.

TABLE II

ORDINATES FOR BALANCED FLAP

(Values in percent flap chord, c_f)

Station	Upper	Lower
0	1.38	1.38
1.25	2.94	.42
2.5	3.72	.23
5	4.85	.03
7.5	5.81	0
10	6.65	0
15	7.81	0
20	8.43	0
30	8.08	0
40	7.00	0
50	6.00	0
60	4.92	0
70	3.84	0
80	2.81	0
90	1.73	0
95	1.07	0
100	.74	0

T.E. radius, 0.37

L.E. radius, .615

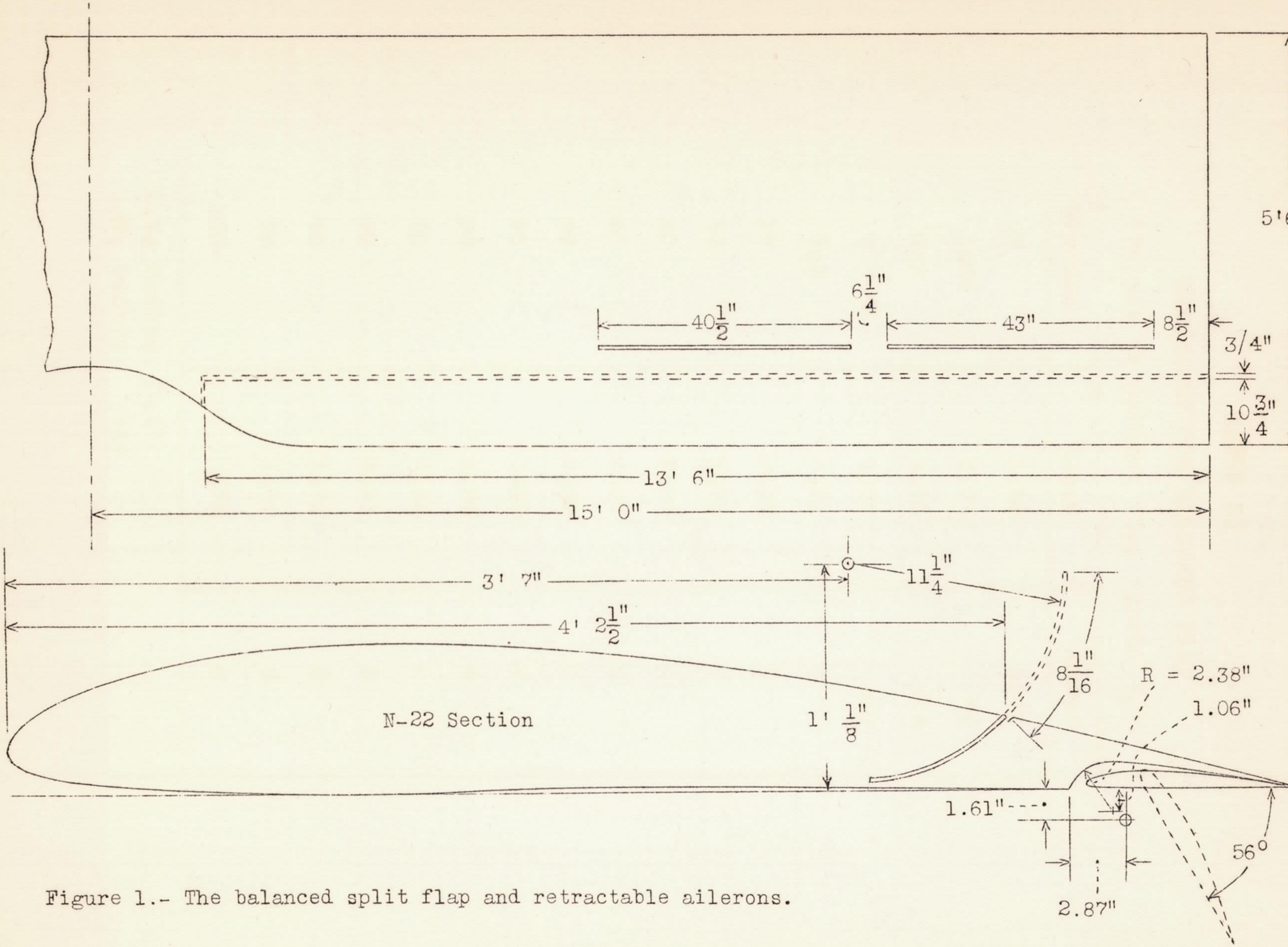

Figure 1.- The balanced split flap and retractable ailerons.

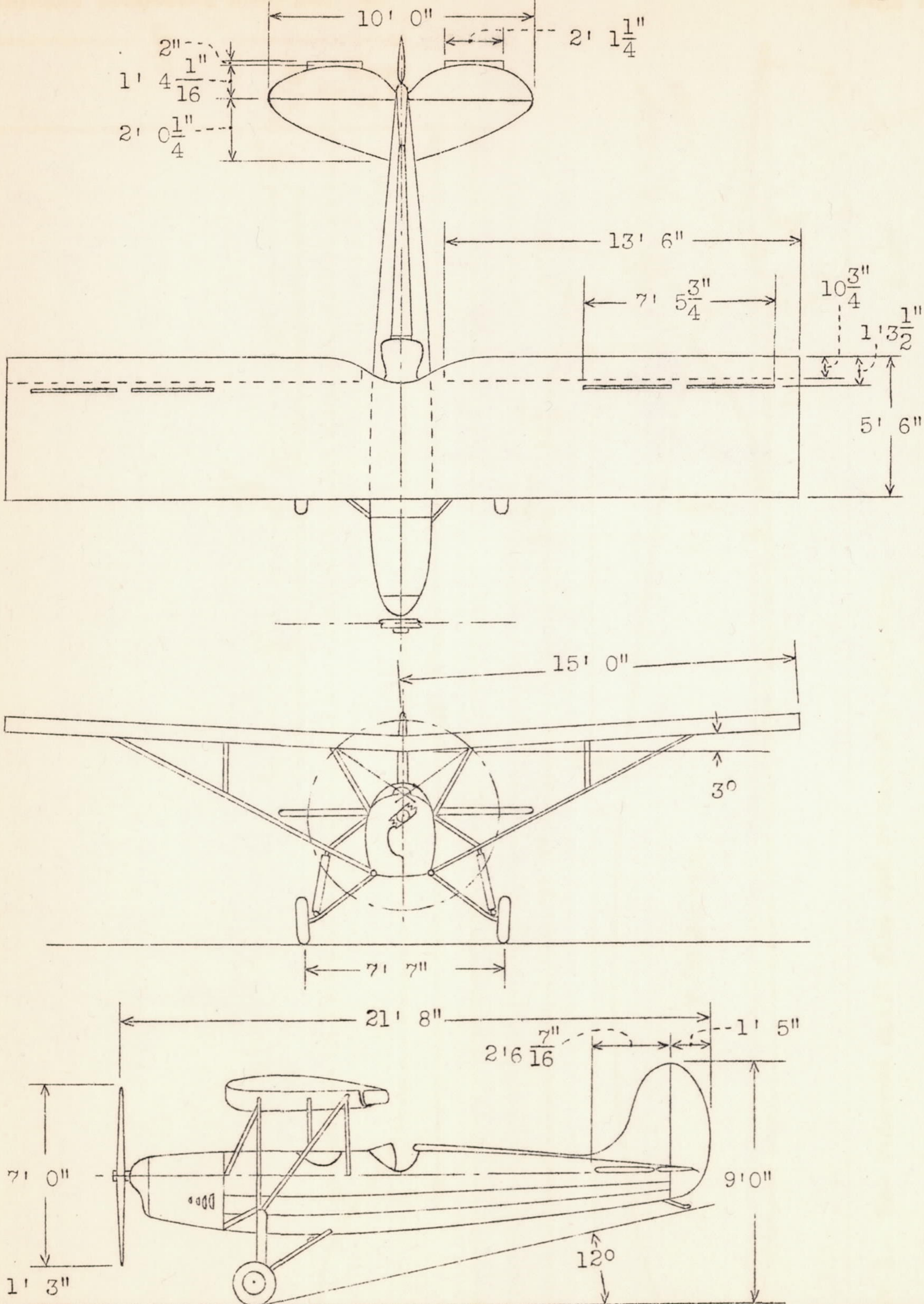

Figure 2.- Three-view drawing of Fairchild 22 airplane as flown.

Figure 3.- Fairchild 22 airplane showing balanced split flap and retractable ailerons

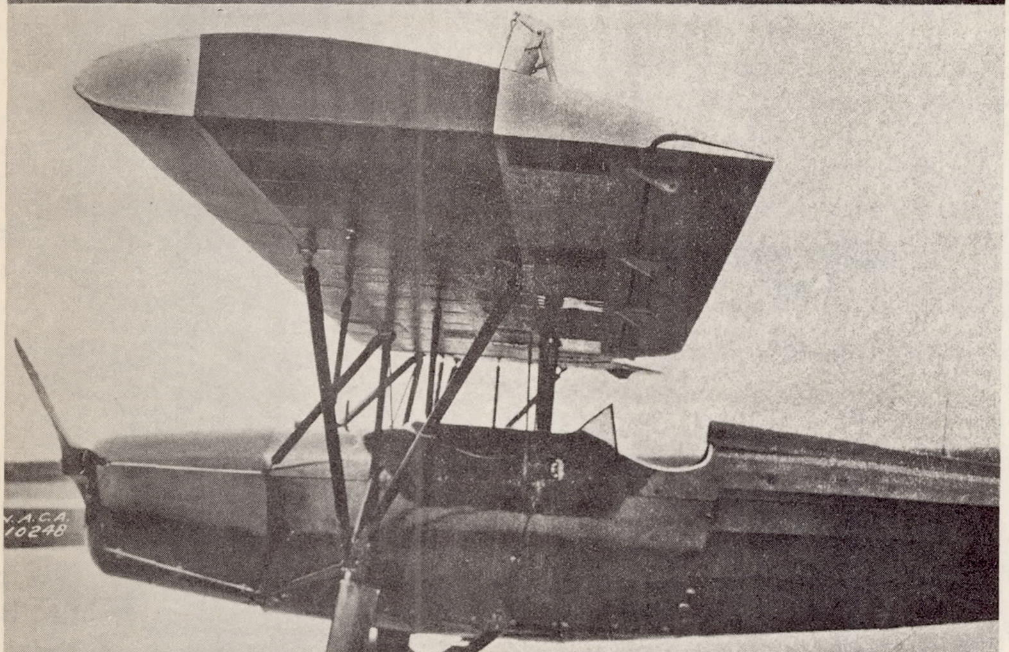

Figure 4.- Balanced split flap retracted

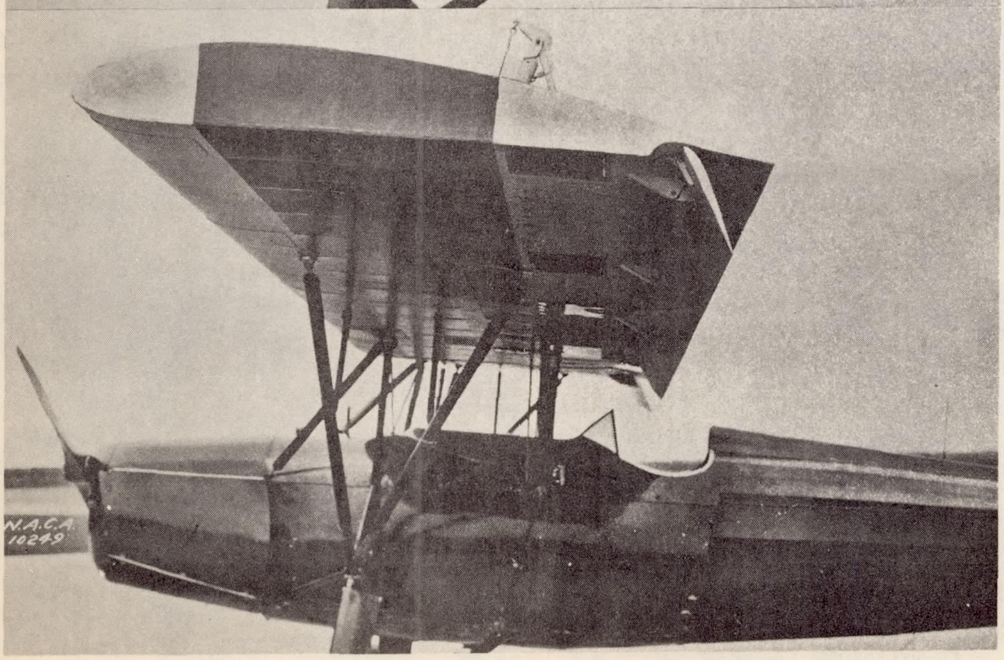

Figure 5.- Balanced split flap extended

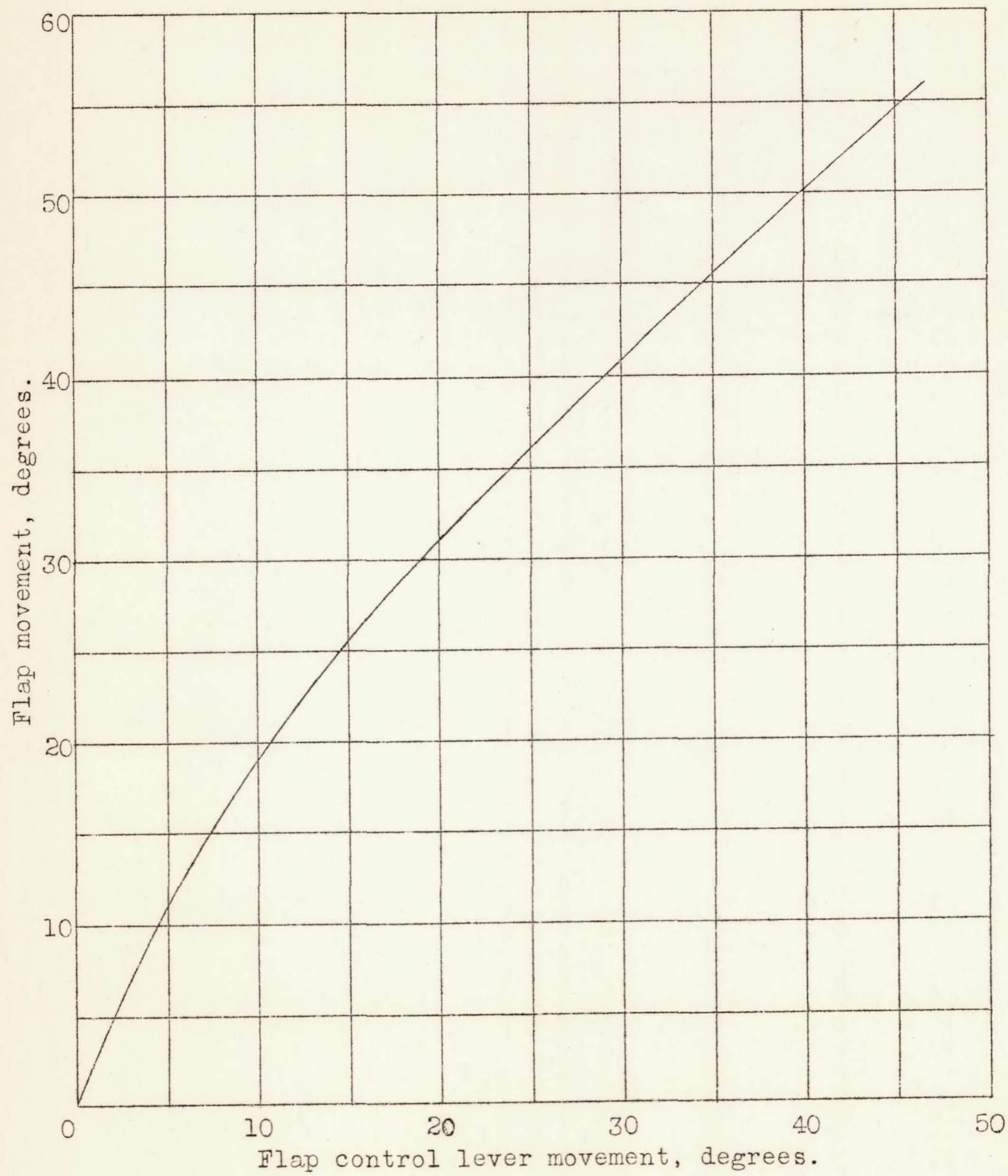

Figure 6.- Relative movement of balanced split flap and flap control lever.

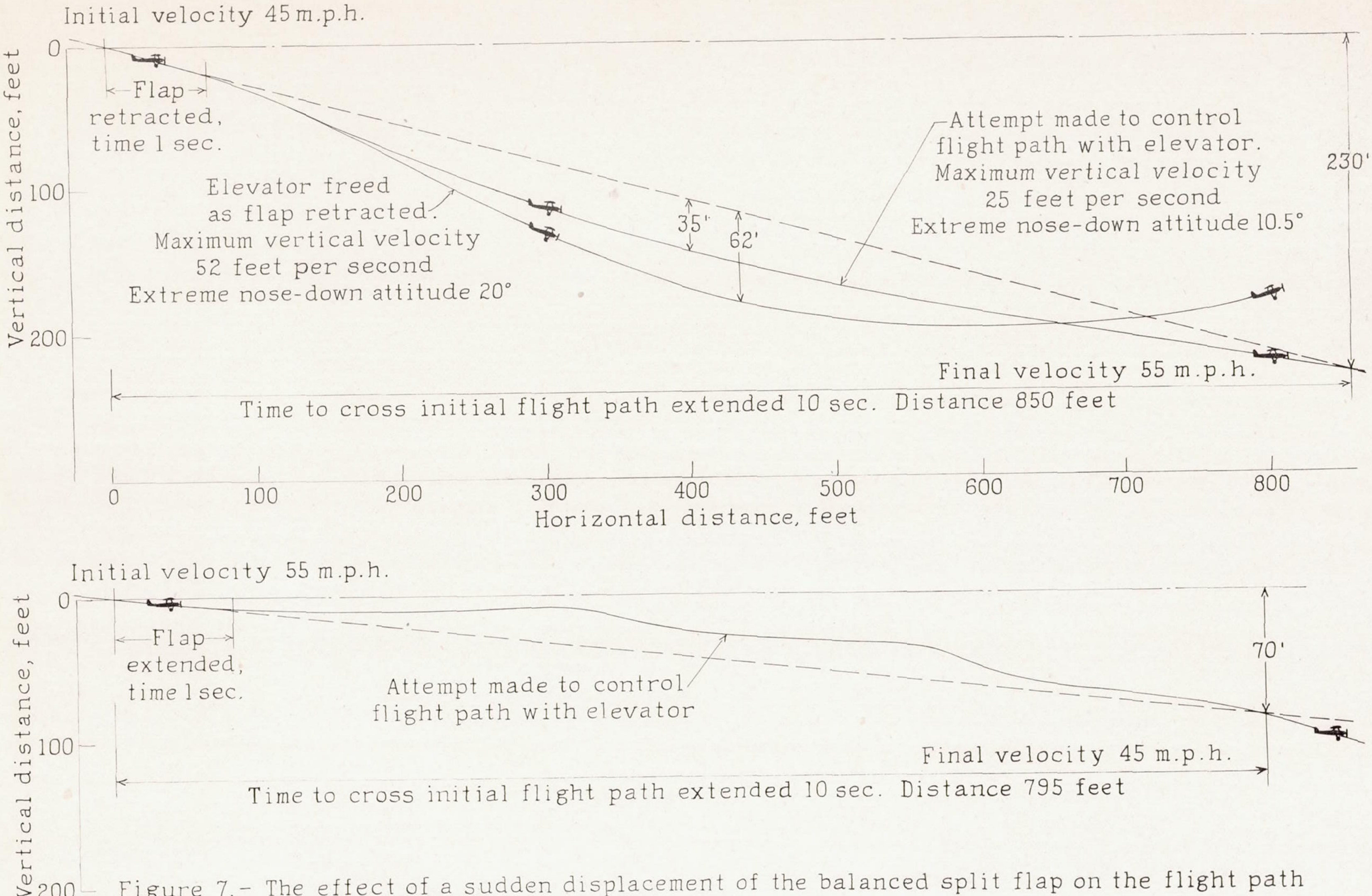

Figure 7.- The effect of a sudden displacement of the balanced split flap on the flight path of the Fairchild 22 airplane.

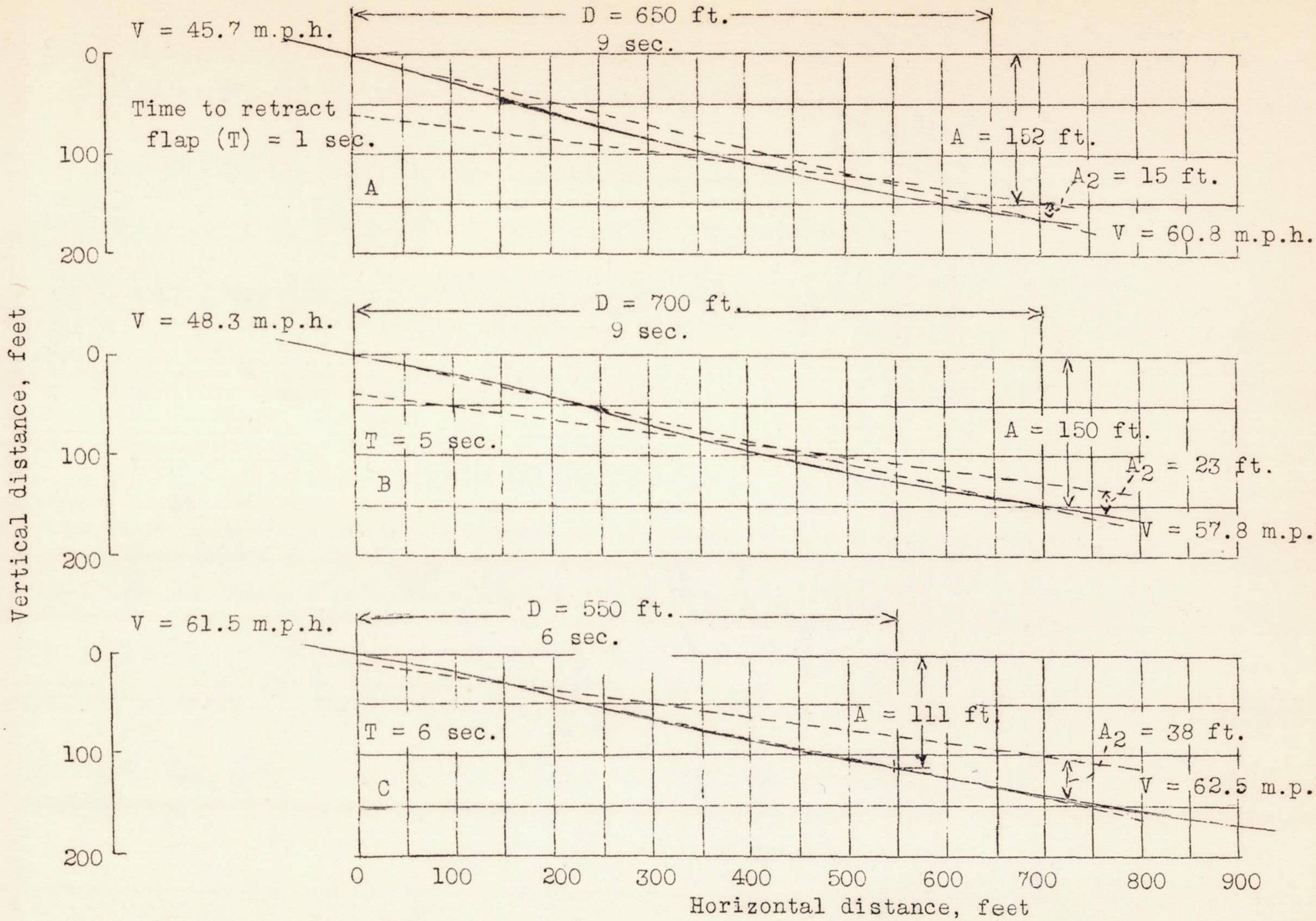

Figure 8,- The effect of retracting the balanced split flap under different conditions.

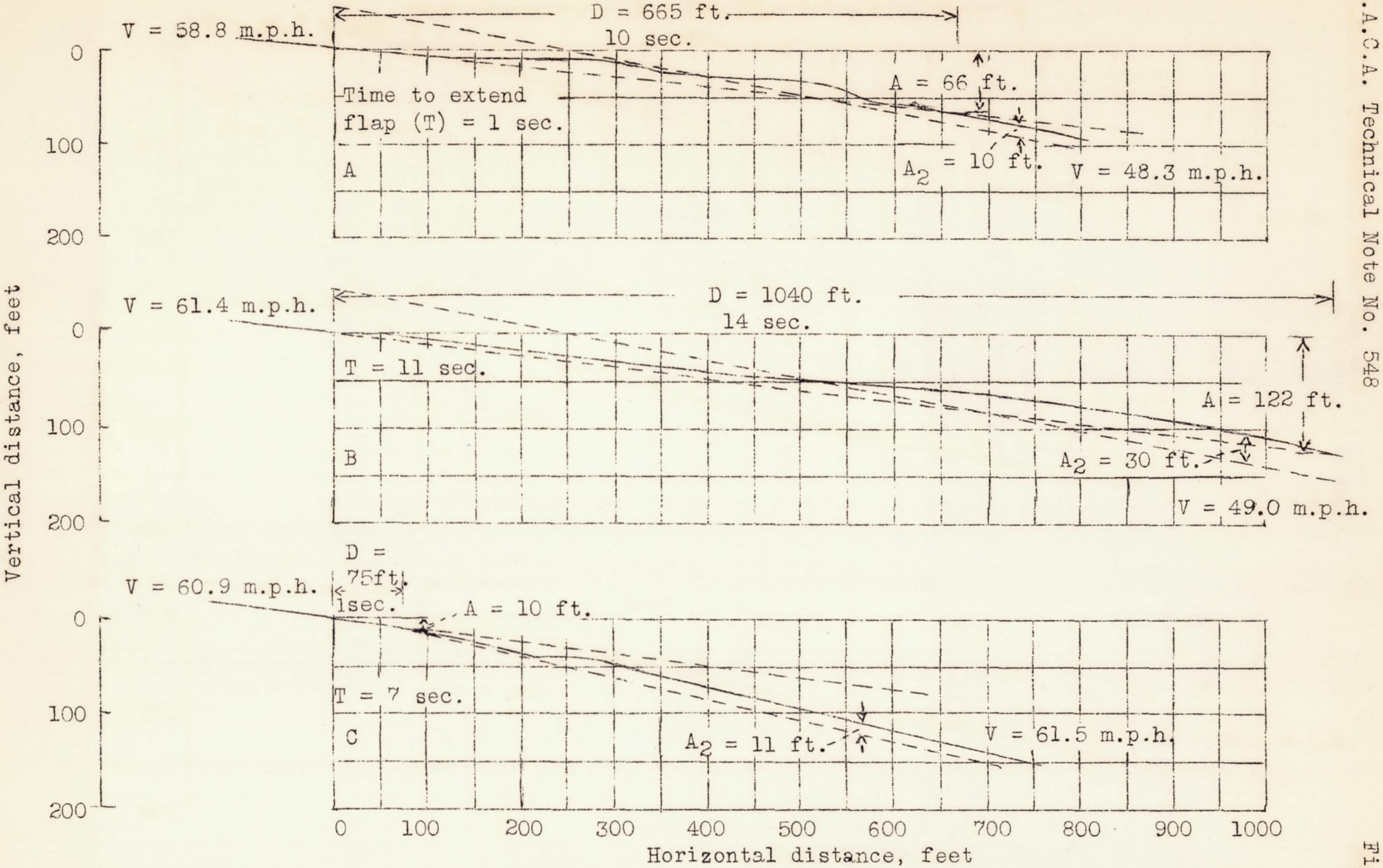

Figure 9.- The effect of extending the balanced split flap under different conditions.

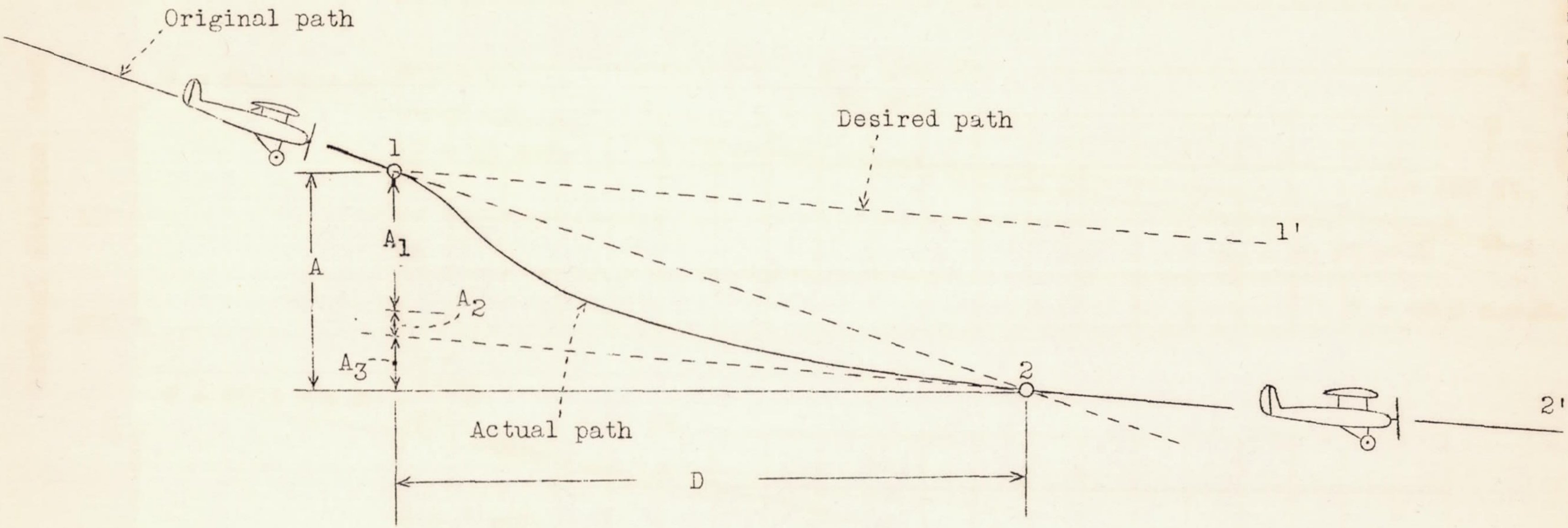

Figure 10.- Schematic drawing of the motion subsequent to retracting the flap at low speed.

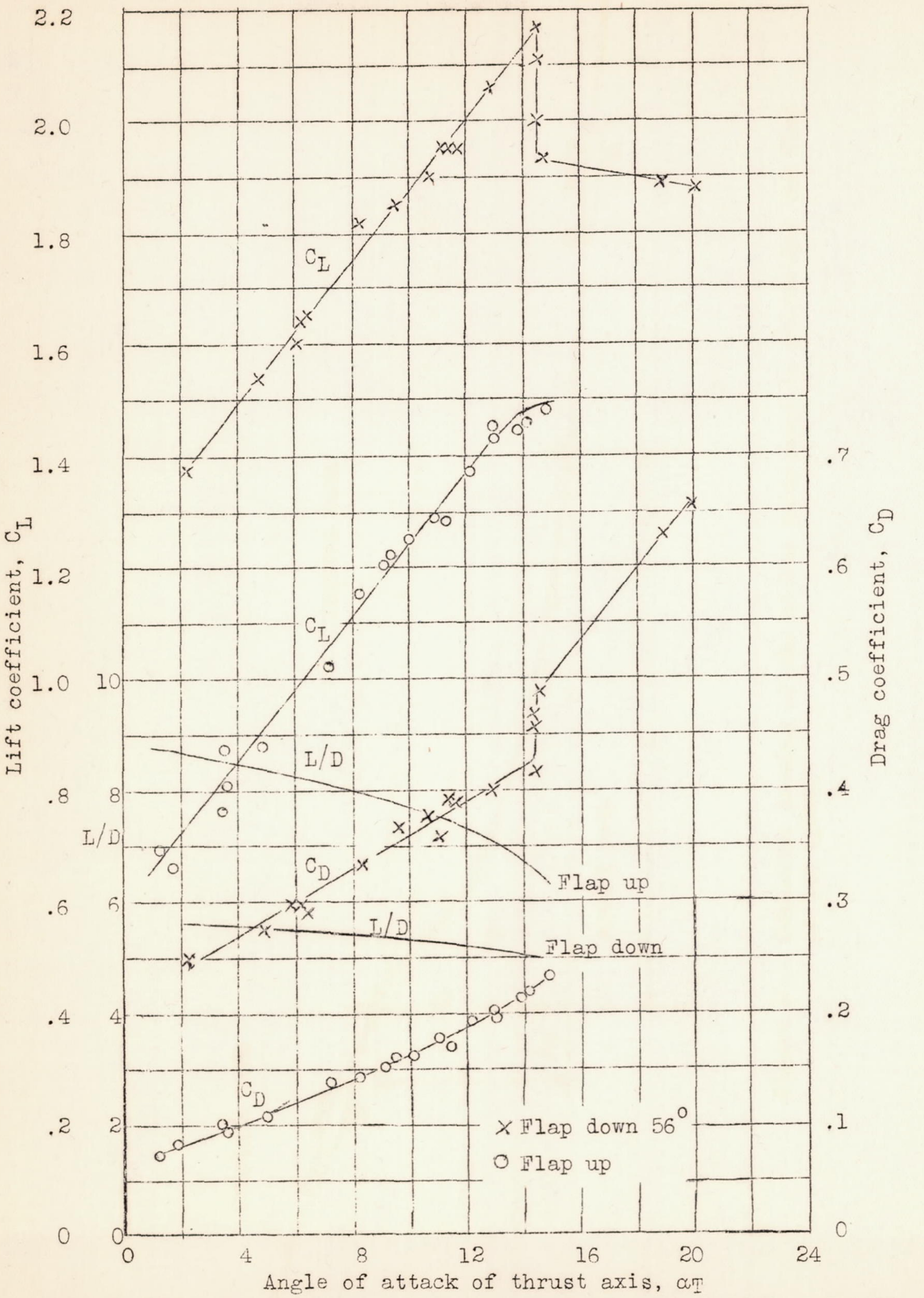

Figure 11.- The lift and drag characteristics of the Fairchild 22 airplane equipped with balanced split flaps.

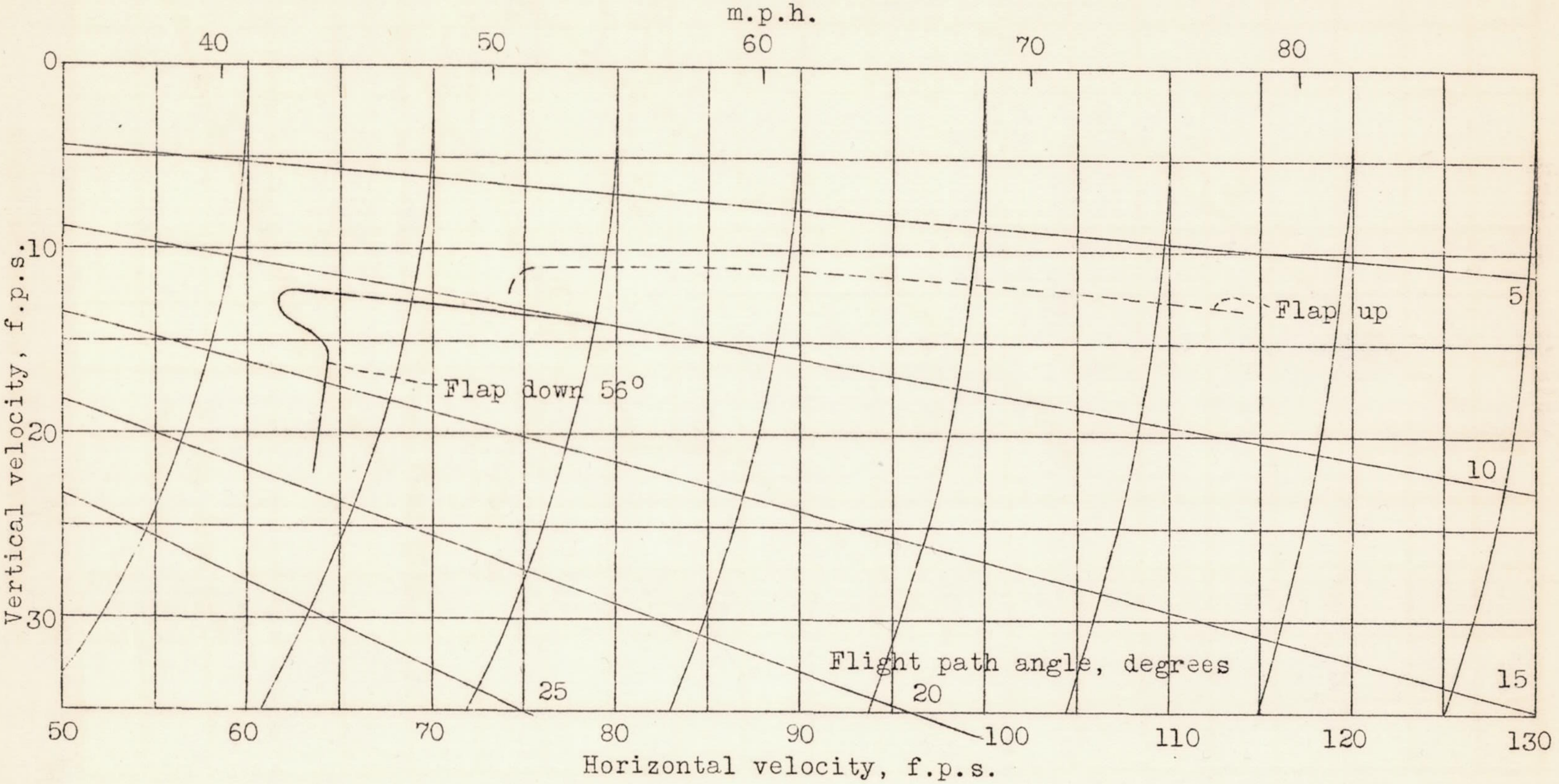

Figure 12.- Velocity diagram of the F-22 airplane with balanced flap.

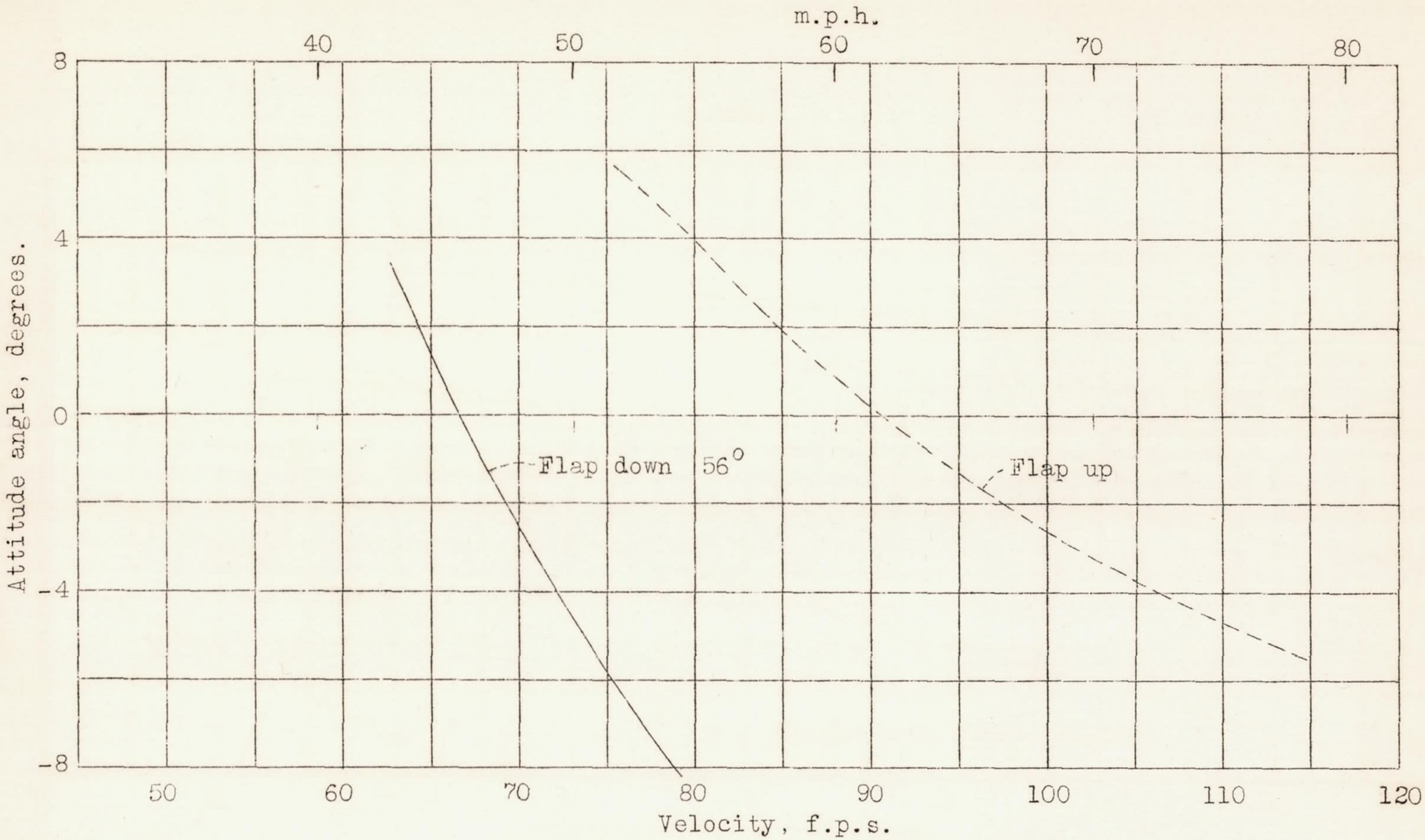

Figure 13.- Effect of the balanced split flap on the attitude angles for gliding flight.

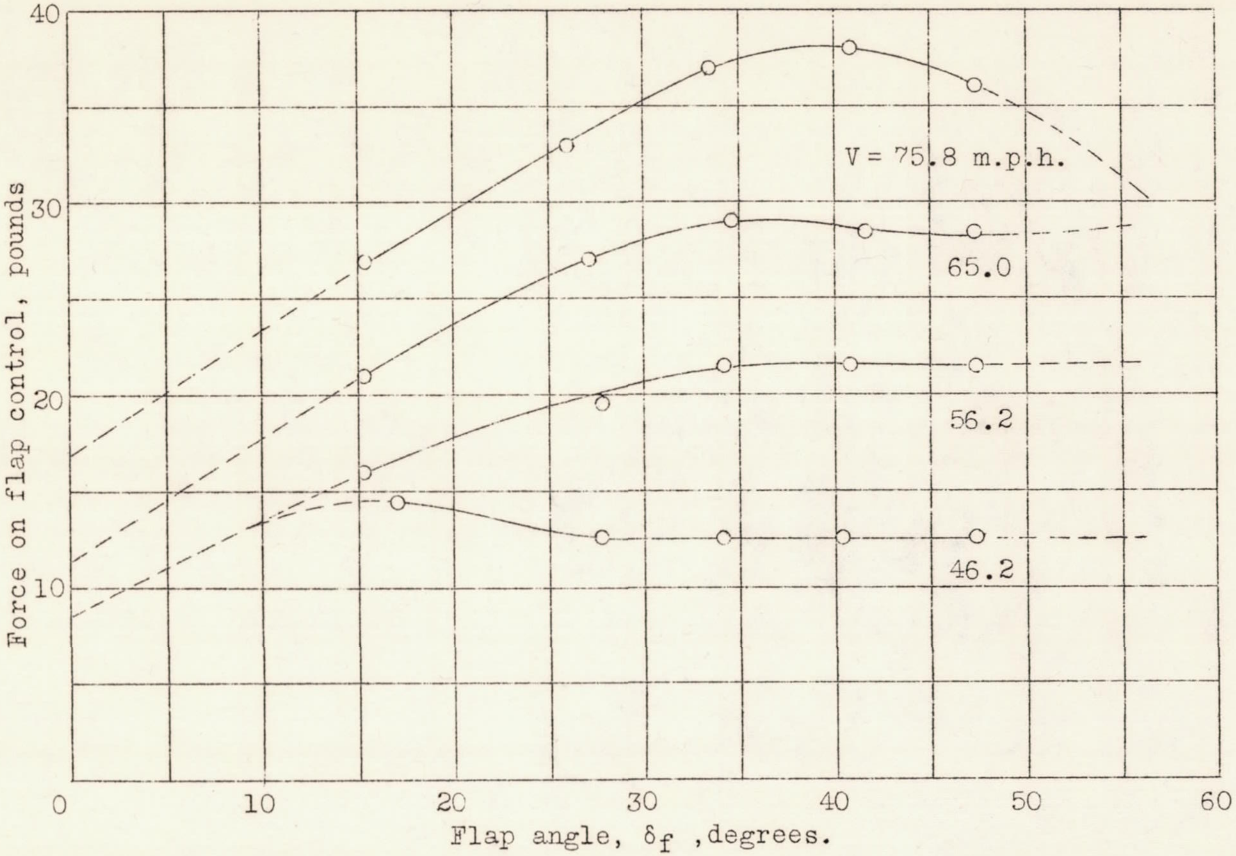

Figure 14.- Force required to operate the balanced split flap.

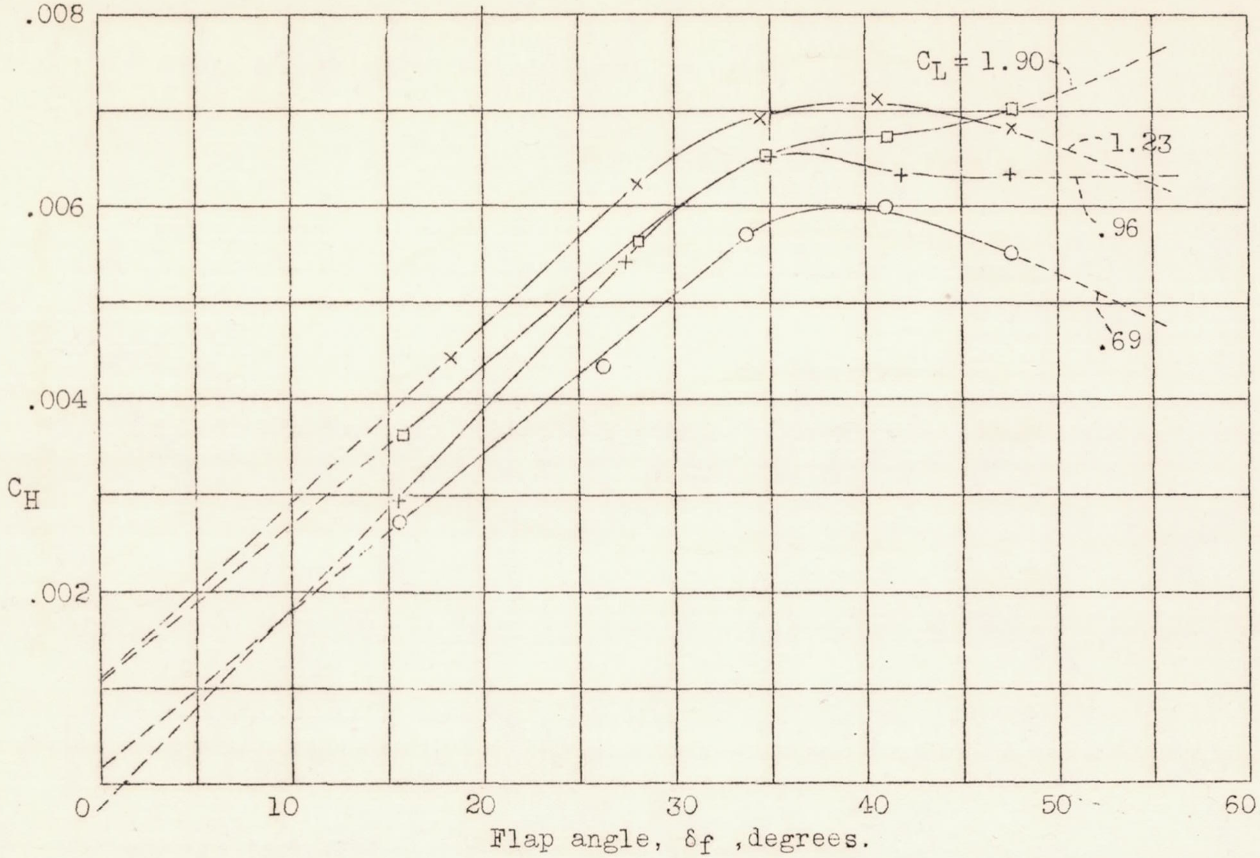

Figure 15.- Hinge-moment coefficients for the balanced split flap.

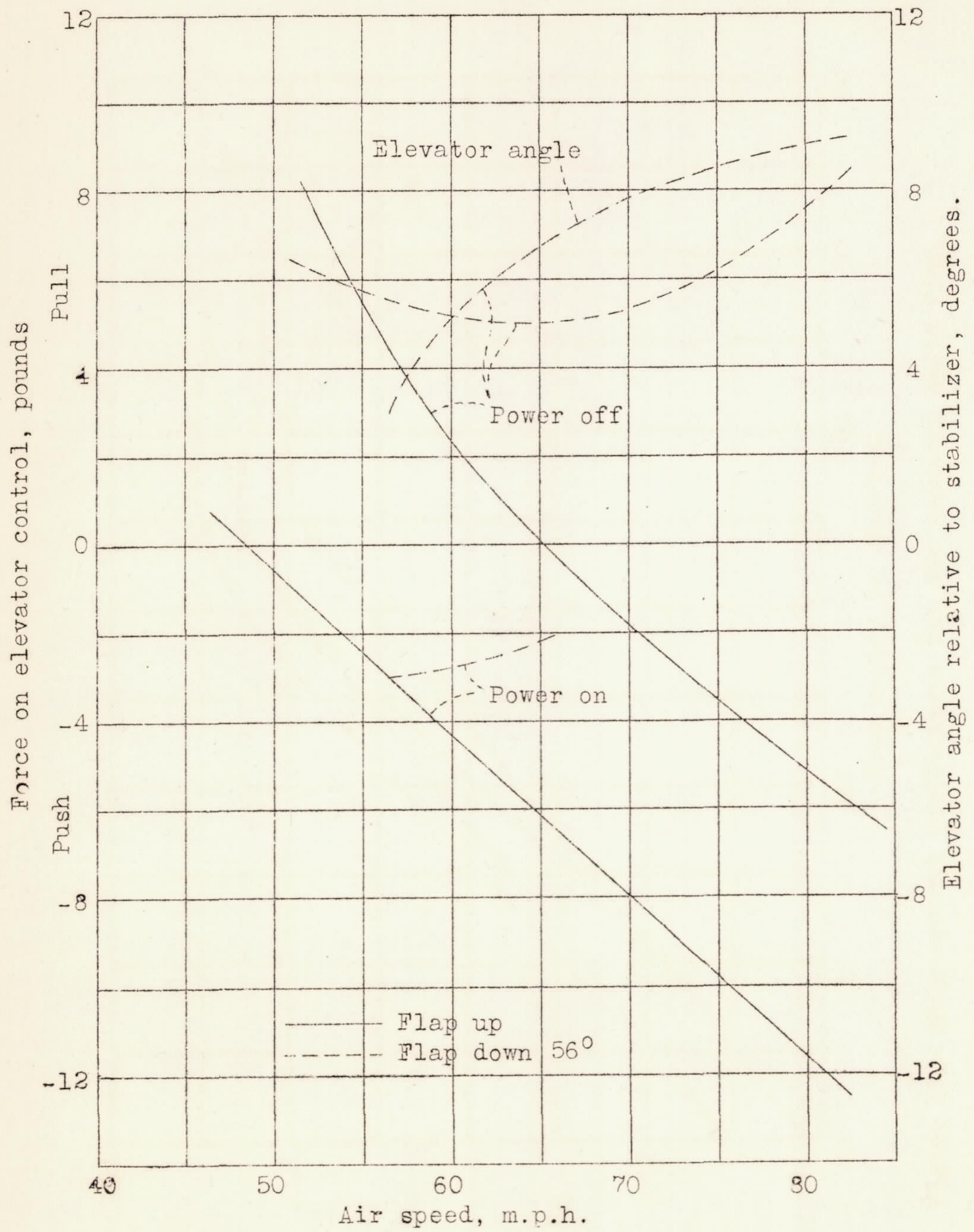

Figure 16.- Variation of control-stick force and elevator angle before installation of elevator tab. Stabilizer -4.0°, c.g. 31.1 percent c.

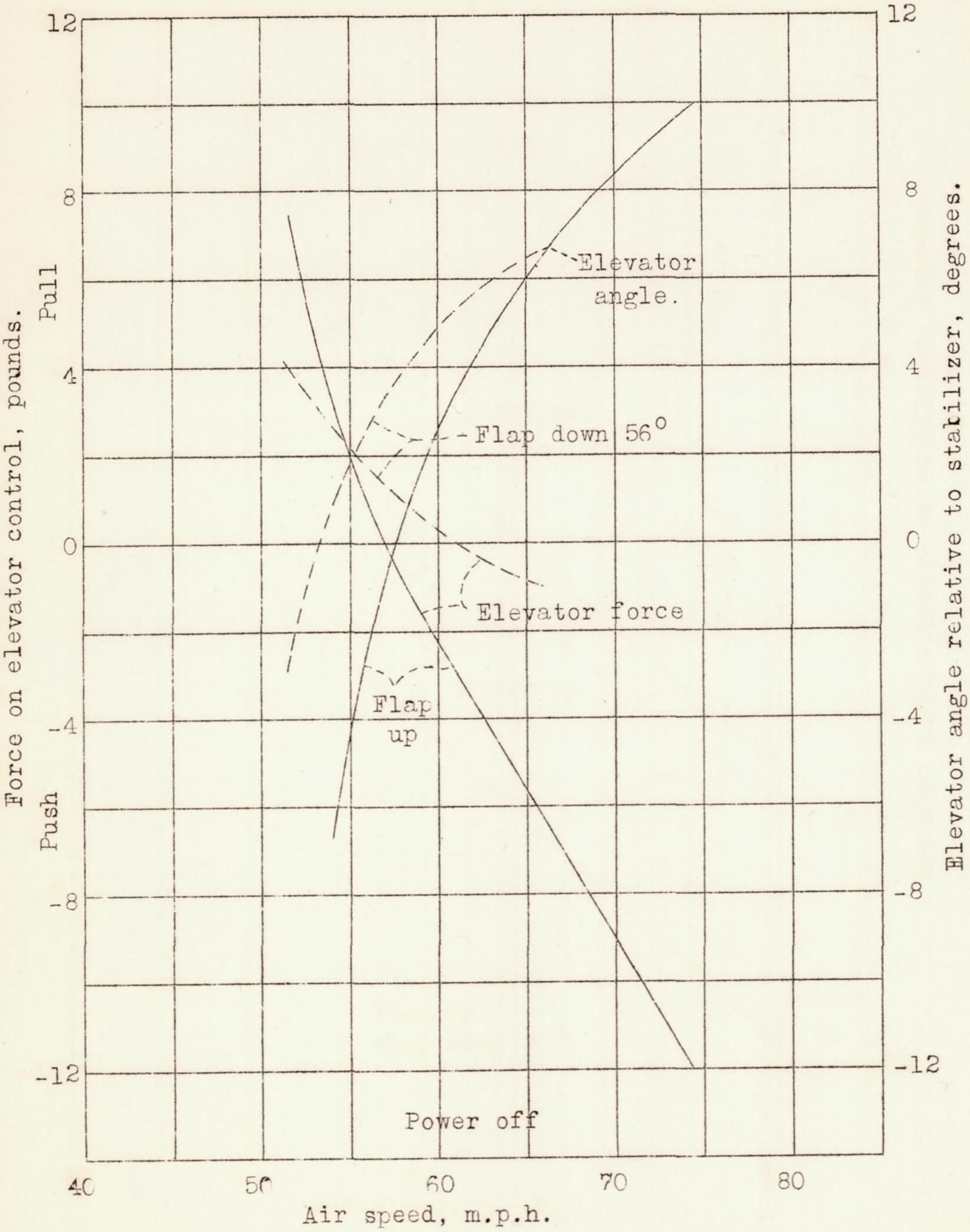

Figure 17.- Variation of control-stick force and elevator angle after installation of elevator tab.
Stabilizer -4.0°, c.g. 31.1 percent c.